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HELICOPTER ROTOR TEST RIG (RoTeSt) IN DNW - APPLICATION AND RESULTS

(HUBSCHRAUBER-VERSUCHANLANGE RoTeSt IM DNW - EINSATZ UND ERGEBNISSE)

by

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SUMMARY

The calibration and operation of the model helicopter test rig, RoTeSt, in DNW is discussed. The choice of calibration factors for the different aspects of the rig is addressed, and a block diagram of the signal flow is given. Wind tunnel tests conducted on various rotors using the rig are reviewed, comparing results between model rotor operation points and full-scale flight states. Comments are made on: the derivative of the longitudinal angle of control as a function of velocity, the correction values for rotor angle of attack for various working section configurations and mast angles, and on the effect of tunnel temperature on the rotor thrust for constant rotor speed. Results are compared for various rotors including accelerations, dynamic momentum behaviour, and measurements of downwash.

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1 INTRODUCTION

Since 1977, the Institute for Aeronautical Engineering has been operating a mobile Rotor Test Rig which has proved its excellence over a number of tests carried out in various wind tunnels (Fig 1).

The rig has to meet the following requirements:

(a) It must be easy to apply the data gained from the wind tunnel tests to wider areas (*eg* rotor and blade dynamics, stat. derivatives).

(b) The data must be comparable with theoretical models (*eg* downwash, trimming conditions, rotor and blade stress).

(c) It must be possible to examine special configurations and effects (*eg* future helicopter projects, reduction of vibration, interference).

(d) Mobility, *ie* the ability to operate in different wind tunnels or working sections.

These requirements make high demands on both model technology and measurement methods.

2 MODEL SCALE

For the model data to be representative of full-scale, the scale factor must be selected so that the aerodynamic and dynamic conditions on the original rotor are reproduced with sufficient accuracy. Production tolerances for the original also apply to the model, scaled down by the scale factor. This places very high demands on modelling technology and consequently the general rule is to choose a model size as near to full-scale as possible.

In choosing the scale factor, the availability of sufficiently large wind tunnels must naturally be taken into consideration: to keep tunnel wall effects as low as possible, the width of the tunnel working section should be at least twice the model rotor diameter. To minimise ground effects, a distance of 1.5 rotor radii from the tunnel floor is recommended. A rotor of 4 m diameter therefore requires a working section of at least 8 m × 6 m. In Germany, this requirement is met by the Daimler Benz and Volkswagen plants wind tunnels. Both these tunnels are mainly used for vehicle measurements and, because of their short return circuit lengths are less suitable for rotor measurements.

Since 1979, the German-Dutch wind tunnel has been available and has offered the best facilities with regard to flow quality, flow speed and selection of working sections for testing helicopter rotors.

When the above-mentioned limiting conditions are taken into account, a scale factor of 2.5 results for scaling the BO 105 main rotor. This factor not only affects the geometric dimensions of the model rotor, but also other physical quantities such as rotational speed, forces and moments.

Thus, for example, the rotational speed must be increased by the factor of 2.5 to obtain aerodynamics similar to the original. This means a correspondingly faster data transmission rate is required.

As model rotor frequencies of up to 140 Hz are to be measured (corresponding to the 8th harmonic), a qualitative comparison of the rotor dynamics of the BO 105 should be possible. In instances where the moments of inertia, mass and stiffness distribution play little or no part, a quantitative comparison is also possible. This requires a detailed knowledge of the natural frequencies and modes of the rotor loads balance so that the harmonics of the rotor forces and moments being measured can be determined with sufficient accuracy (Fig 2).

The requirements for data acqusition result mainly from the high transmission rate for frequencies of up to 140 Hz. Since 64 channels have to be scanned with a 10 bit resolution, the transmission speed amounts to 500 kbits/s. This requires the application of modern computers and computer peripherals (array processor, graphic terminal, etc) for on-line data processing and plotting of certain signals.

Fig 3 shows the signal flow for the rotary system (rotor) and the fixed system (rotor load balance and peripherals).

All the data are transmitted as PCM words (PCM = Pulse Code Modulation) over 1.5 seconds = 25 revolutions. For the "Quick Look" evaluation in the wind tunnel, only one rotor revolution is evaluated at a time to achieve the necessary speed. Because of the large quantity of data in the time domain, the Quick Look is made clearer by plotting in the frequency domain, showing amplitude and phase. This also applies to off-line evaluation which also offers the possibility of comparing data from different test series. Storage of data in the frequency domain affords a 95% reduction in data storage.

3 WIND TUNNEL TESTS

Up to now, most test programmes have been directed at operating points of the BO 105. When measuring performance parameters, interpolations can be made between the test points in the tunnel and operating points obtained in flight test. Fig 4 shows the range which was covered during a test series and comprises roughly 500 points.

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To obtain as much information as possible, the control parameters (collective, longitudinal and lateral cyclic control angles), the rotor shaft angle α_{RO} and the tunnel speed are vaied independently of one another.

Tests to determine derivative measurements are carried out for a direct comparison with the BO 105 rotor. Starting from the control angles of the BO 105 for hover flight conditions, parameter variations are made and the ensuing changes in the forces and moments of the rotor and rotor blades measured. This leads to significant insights into the behaviour of the rotor, *eg* at different speeds as in Fig 5.

The original trimmed condition of the BO 105 cannot be directly transferred to the wind tunnel model, since - apart from the effects of the tail rotor and fuselage on the control parameters - wind tunnel effects also play a considerable part.

Fig 6 shows the necessary correction figures for the rotor shaft angle, α_{RO} from theoretical examination. Accordingly, for measurements in the closed working section at low speeds, the rotor shaft angle (rotor incidence) must be corrected by 10° to simulate hovering flight ($\alpha_{RO} = 0$) in the wind tunnel. Experience of the DFVLR has shown that the theoretical curves are set too low by approximately 5°. It is certainly important to conduct basic investigations into "wind tunnel interference".

Tests of the BO 105 scaled model rotor in the DNW, with the different working sections available (6 × 6 m, 8 × 6 m, 9.5 × 9.5 m closed; 8 × 6 m open), offers the best opportunity for obtaining comparative results which will permit theory to be widely applied.

As regards measurements of the load conditions of the rotor and the rotor blades, the blade tip Mach number Ma_{Tip} must be retained, since it is only in this way that the dynamic scaling laws will be followed. The rotational speed of the rotor must therefore be adapted to the tunnel temperature and static pressure. Fig 7 shows the change in the standard thrust with a constant rotational speed as a function of the temperature. A change in the tunnel temperature of 15°C means - if the rotational speed is kept constant - the rotor thrust will be 6% in error.

The calibration coefficients of the rotational speed harmonics - especially those from the rotor loads balance - must therefore take into account the fact that the operating rotational speed of the rotor is not a constant quantity.

4 RESULTS

Besides the static loads (stat. derivatives in Fig 5) already shown, the dynamic loads measurements are of considerable interest, since they supply information on the dynamic characteristics of the rotor. While it is true that quantitative comparisons between the original and the model are not always possible on account of the different distributions of mass and stiffness of the total system, the results do yield qualitative information on dynamic behaviour.

Fig 8 shows a comparison between the BO 105 and a model rotor with modified dynamics and aerodynamics. The 4th rotor harmonics are recorded for acceleration close to the rotor head.

It is evident that the maximum is in the range of $\mu = 0.1$ (= 22 m/s) normal to the flight direction. In this range, the effect of the tip vortices is greatest, since at low speeds the upward flow in the front area of the rotor is greater than at higher forward speeds and keeps the vortices close to the rotor disc for a longer time.

The BO 105 and Research Rotor 2 have the maximum at the same point, yet an increase in the vibration level is again evident with the BO 105 with $\mu > 0.15$. In the case of research rotor 2, this increase is not apparent until $\mu = 0.3$ (= 66 m/s) because of the improved blade profile, chiefly in the area of the blade tip, and better blade geometry. In general, the pitch link loads are greater in the case of the research rotor 2, since the blades exhibit greater shearing forces on the rotor plane, on account of their greater mass. The higher inherent torsional frequency of these blades is another contributing factor.

Fig 9 shows the dynamic behaviour for two model rotors. It shows the 4/rev rolling and pitching moments for various speeds as a function of the blade's azimuth angle. These Lissajous figures show the proportions of the two moments while the rotor makes one revolution. It can be seen that the rolling moment $M_{x,4rev}$ possesses the higher figure over the entire speed range - an effect mainly attributable to the flapping movement of the rotor blade.

The eccentricity of the ellipses gives the phase differences of the moments in relation to each other; if $\partial\psi = 0$ or $\partial\psi = 180°$, the ellipses then degenerate into a straight line. Here the maximum of the dynamic range can be seen at v = 20 m/s. In the high speed range, the research rotor 2 exhibits a considerably lower dynamic range than research rotor 1 - proof that compressibility effects up to 66 m/s with the research rotor 2 have a lesser effect.

Fig 10 shows the downwash as measured under the rotor at ψ = 0, 90, 180 and 270°. The measurements at ψ = 90 and 270° differed only very slightly from each other (which must be the case with a trimmed rotor) so that a second series of curves could be dispensed with. With ψ = 0° (behind) and ψ = 180° (in front) differences in the induced downwash velocity occur. This trend is demonstrated even more clearly in theory where there is an up-wash predicted in the forward area of the disc.

Subsequent calculation, represented by the lines in Fig 10, does not take into account any blade distortion, thereby yielding differences between calculation and measurement. Since downwash is determined mathematically in the plane of the blade, while the measuring probe is a distance outside the blade plane, the measurement and calculation results at the sides are very different. Furthermore, there is not sufficiently accurate knowledge of wind tunnel interference which exercises a strong influence on the downwash.

Even if special effects are not taken into account in subsequent calculation, the aerodynamics of the rotor can be interpreted very well by comparison of measurements with calculation.

5 FUTURE WORK

In the main, the following work is aimed at achieving improvements in wind tunnel measurements on rotors and helicopters:

(i) Reduction of interference caused by the test assembly.

(ii) Refinement of model and measurement technology.

(iii) Better knowledge of interference caused by wind tunnel.

In the near future, further improvements will be made to points (i) and (ii): in conjunction with MBB and commissioned by the BMVg, the DFVLR is constructing a wind tunnel model which is fixed to the DNW sting mount and hence offers the possibility of being positioned in various working sections without alterations to the model or to the model's suspension. Point (iii) could then, with corresponding financial backing, also be elaborated.

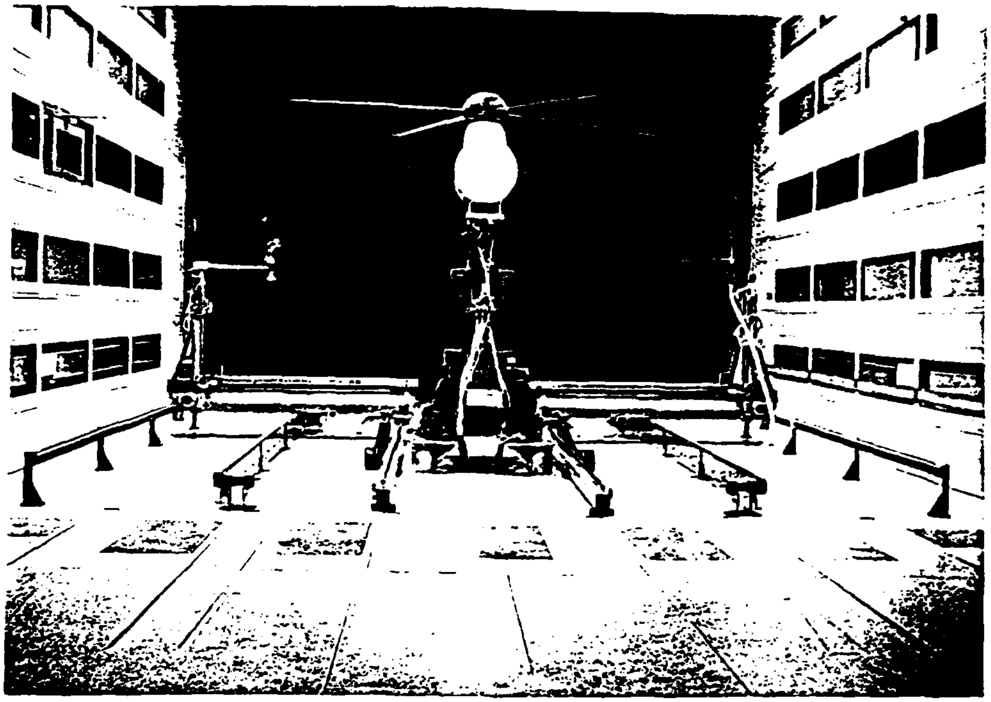

Fig 1 DFVLR rotor test stand in the DNW

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Fig 2

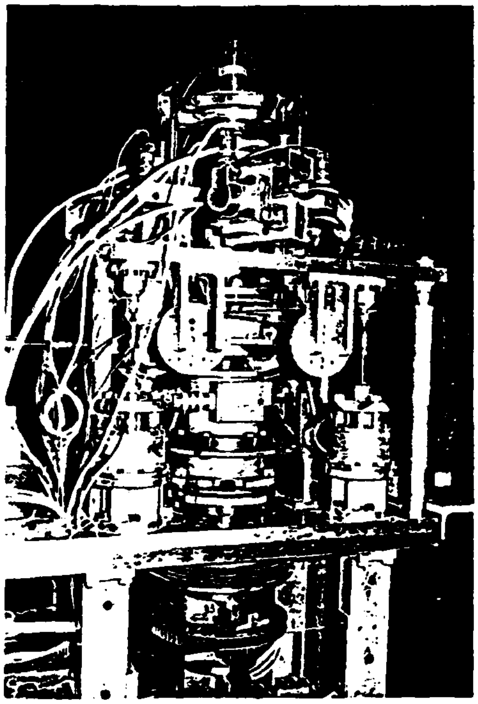

Fig 2 Rotor loads balance and hydraulic controls

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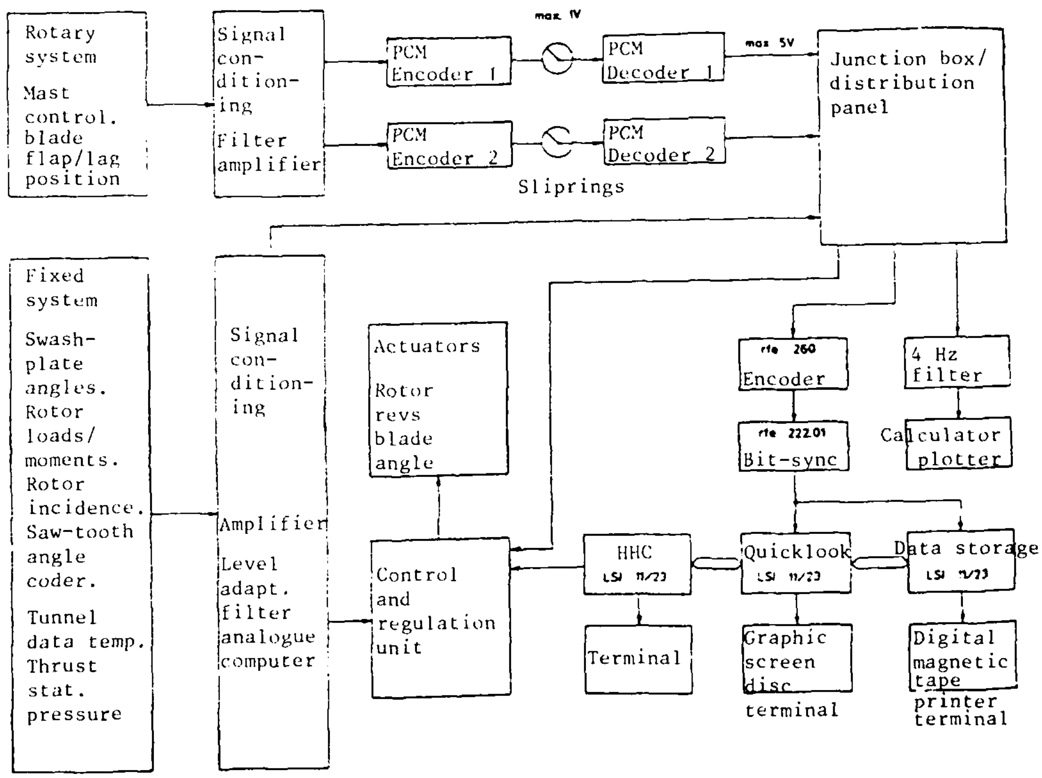

Fig 3 Signal flow on the rotor test stand

Fig 4

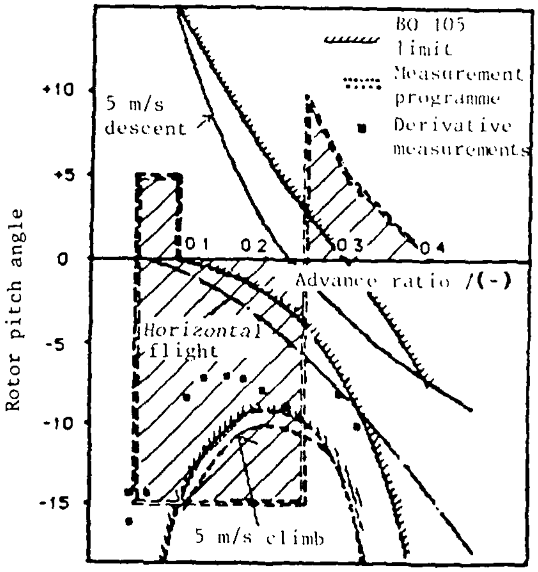

Fig 4 Relationship between operating points of the model rotor and flight conditions of the BO 105

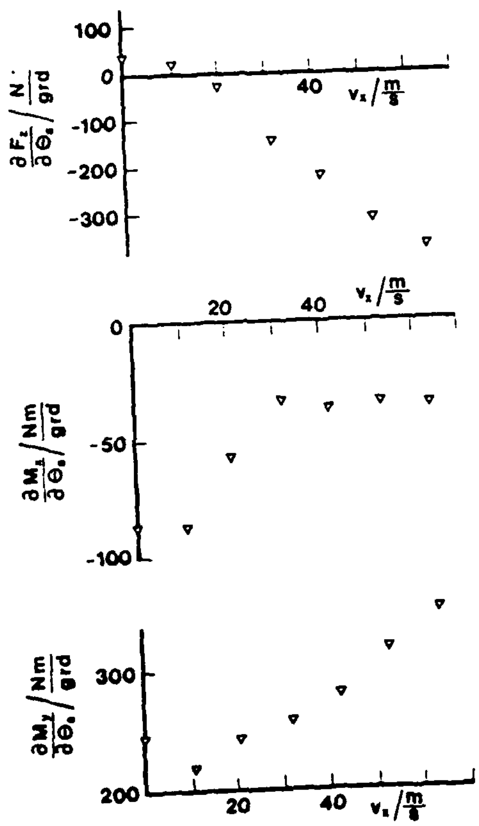

Fig 5 Longitudinal control angle derivative as a function of speed

Fig 6

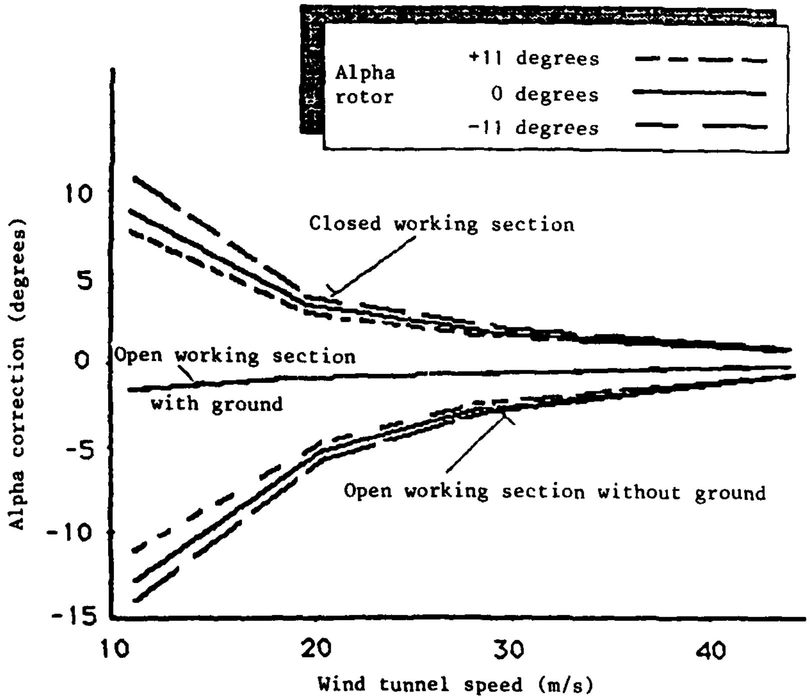

Fig 6 Correction factors for rotor incidence with different working section configurations and shaft tilt angles

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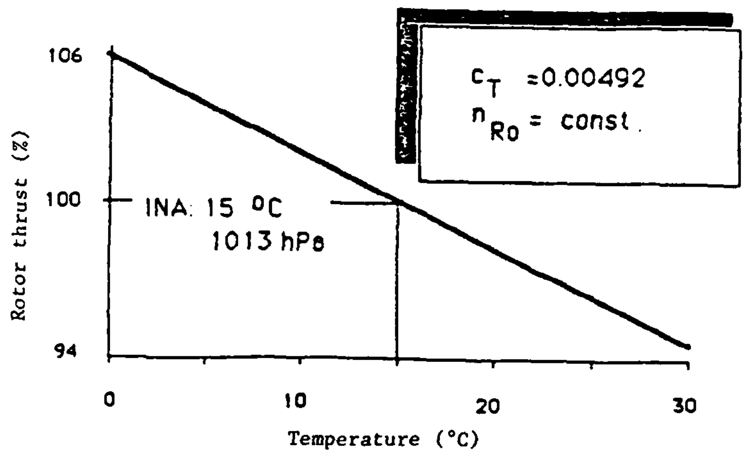

Fig 7 Effect of tunnel temperature on rotor thrust for a constant rotational speed (C_T at ISA)

Fig 8

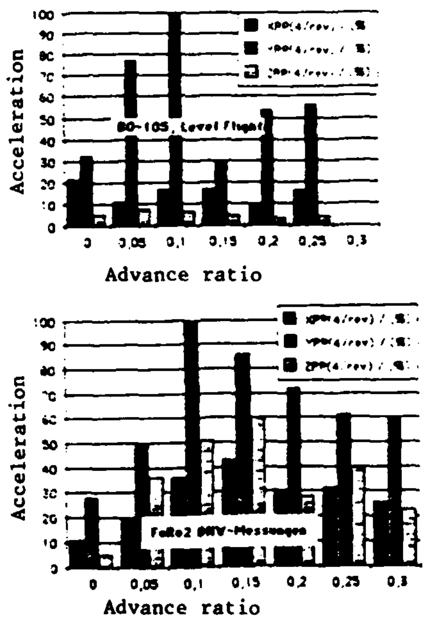

Fig 8 Acceleration measurements from flight and wind tunnel tests (related to the maximum figure at v = 22 m/s, 4th rotor harmonic)

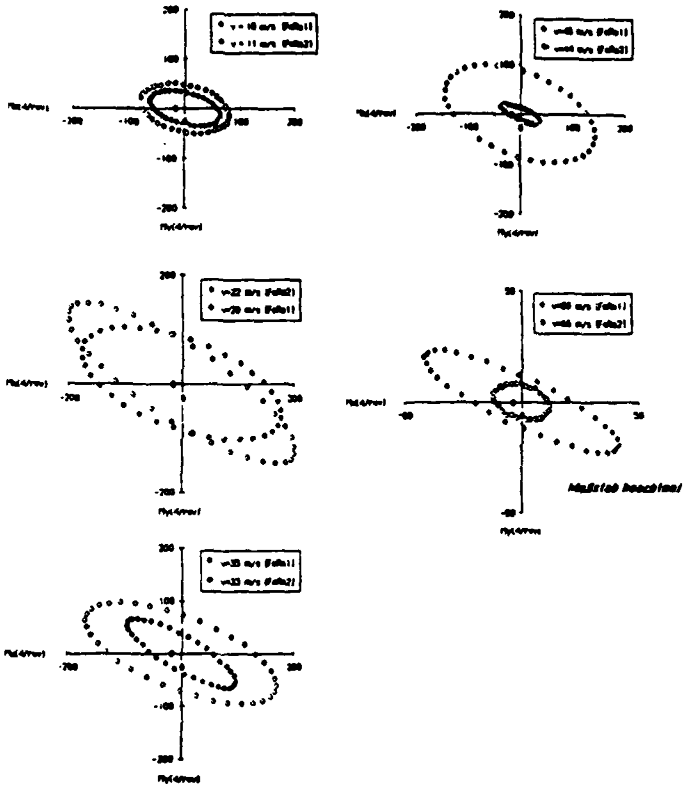

Fig 9 Results from wind tunnel tests - dynamic moment behaviour of non-articulated rotors (research rotor 1 = BO 105 scaled)

Fig 10

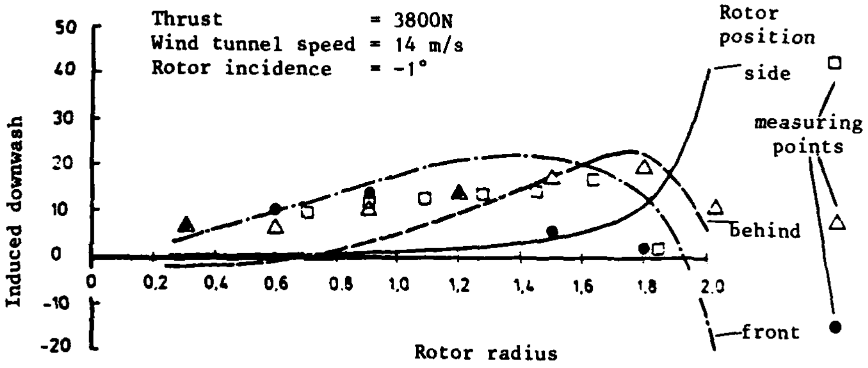

Fig 10 Downwash measurements in DNW under a 4-bladed rotor